egusphere-2024-320
"Quantifying the Impacts of Atmospheric Rivers on the Surface Energy Budget of the Arctic Based on Reanalysis"
Response to the Reviewers

By Chen Zhang, John J. Cassano, Mark Seefeldt, Hailong Wang, Weiming Ma, and Wen-wen Tung

We appreciate the valuable comments provided by the Reviewers. Before addressing each point individually, we would like to acknowledge the two common concerns raised by Reviewers.

Firstly, there were concerns regarding the methodology of our analysis. The primary objective of this work is to estimate the relative contribution of different surface energy budget (SEB) components to the net SEB. To achieve this, original panel (c) in the Figures 2-3, 5-7 of the manuscript aims to illustrate the relative AR contribution to SEB components, normalized by the net SEB. This normalization involves calculating the ratio of the accumulated AR SEB term, which accounts for both the magnitude of individual AR anomalies and their frequency of occurrence, to the accumulated seasonal net SEB. By adopting this normalization approach, we enable consistent comparisons across different SEB components, thereby allowing readers to discern relative contributions effectively.

Furthermore, following RC3's suggestion with a slight modification, we chose to calculate the relative contribution of AR-related SEB component anomaly normalized by the mean of each respective component. This approach aims to estimate the accumulated AR contribution of SEB component relative to their total values. We chose to present the results as an additional panel, now labeled as new panel (c), in Figures 2-3, and 5-7 of the revised manuscript. Consequently, the original panel (c), depicting the AR SEB contribution normalized by the total SEB, has been reassigned to panel (d) to accommodate this adjustment.

Specifically, the results shown in new panel (c) result from the following calculation at each individual grid point within the study domain for each season:

1. Calculate the total extra energy contributed by each SEB component when ARs are present as, $(\mathrm{F_{AR}} - \mathrm{F_{All}}) * \mathrm{t_{AR}}$, where $\mathrm{F_{AR}}$ represents the mean of any term in the SEB equation when an AR is present, $\mathrm{F_{All}}$ denotes the seasonal mean of any term in the SEB equation, and $\mathrm{t_{AR}}$ indicates the total number of 3-hourly time steps during which ARs are present.
2. Calculate the total energy for each component as, $\mathrm{F_{All}} * \mathrm{t_{All}}$, where $\mathrm{t_{All}}$ signifies the total number of 3-hourly time steps within each season.
3. Determine the ratio of these two terms, which provides an estimate of the magnitude of AR anomaly for each SEB term relative to the average value for each component. This is

presented in Eq. (2), noting that the ratio of t_{AR} to t_{All} is simply the AR frequency shown in Fig. 1

$$\frac{(F_{AR}-F_{All}) * t_{AR}}{F_{All} * t_{All}} = \frac{\text{panel (b)} * \text{Fig.1}}{\text{panel (a)}} \quad (2)$$

Additionally, we include the net SEB equation in the revised manuscript, labeled as Eq. (1), as follows:

$$\text{net SEB} = \text{LWN} + \text{SWN} + \text{TH} = \text{LWD} - \text{LWU} + \text{SWD} - \text{SWU} + \text{SH} + \text{LH} \quad (1)$$

Where LWN, SWN and TH denote the net longwave radiation, net shortwave radiation, and turbulent heat flux, respectively. LWD, LWU, SWD, SWU, SH, LH represent downward longwave, upward longwave, downward shortwave, upward shortwave, sensible and latent heat flux, respectively.

Secondly, two Reviewers expressed concerns about the organization of our sections, particularly noting overlapping discussions between Section 3 (Analysis and Results) and Section 4 (Discussion). To address this issue, we have restructured the sections as follows:

- Section 3: AR occurrence frequency (original Section 3.1)
- Section 4: AR's influence on the surface energy budget component of the Arctic (original Section 3.2)
  - Section 4.1: Surface radiative fluxes (original Section 3.2.1)
    - Section 4.1.1: Surface downward longwave radiation
    - Section 4.1.2: Net Surface longwave radiation
    - Section 4.1.3: Net Surface shortwave radiation
  - Section 4.2: Surface turbulent heat fluxes (original Section 3.2.2)
  - Section 4.3: Net Surface energy budget (original Section 3.2.3)
- Section 5: AR's surface impacts
  - Section 5.1: AR-induced surface and air temperature response (original Section 4.1)
  - Section 5.2: AR's crucial role in triggering Greenland Ice Sheet melt (original Section 4.2)
- Section 6: Uncertainties and limitations
  - Section 6.1: Influence of AR detection methods on results (original Section 4.3)
  - Section 6.2: Limitation of the reanalysis data (original Section 4.4)
- Section 7: Conclusions (original Section 5)

We believe these adjustments will enhance the clarity and coherence of our manuscript, addressing the concerns raised by the Reviewers effectively.

Below, we respond in blue text to the Reviewer's comments, using an italic font to indicate text that has been copied verbatim from the Reviewer's reports.

Reply to RC3:
We appreciate the Reviewer for insightful and detailed reviews. We have made changes to the manuscripts, accordingly, as replied below.

RC3:
In this paper, authors aim to analyze the contribution of atmospheric rivers (ARs) to the seasonal surface energy budget (SEB) in the Arctic using ERA5 reanalysis data for 1980-2019. ARs are detected using the 85th percentile of IVT and components of the seasonal SEB are anomalies are assessed for times when ARs are detected. The aim of improving understanding the importance of ARs in net SEB in the Arctic is important and interesting, and the authors provide a very detailed analysis with discussion of implications and connections to previous work. Analysis regarding absolute anomalies is thorough, but I am unsure of the appropriateness of the metric used to quantify the contributions of ARs to seasonal SEB (detailed in Major Comment 1).

Reply: We appreciate the Reviewer's dedication to scrutinizing our metric and proposing new approaches to evaluate the contributions of ARs to net SEB.

Major Comments:

1. *The metric used for evaluating the contribution of ARs to net SEB may not be appropriate for the conclusions drawn. It is difficult to interpret the physical meaning of the contributions when the seasonal net SEB is very small. Please see the attached file for a description of a potential solution and further reasoning. Regardless of how the authors proceed, the equation used to calculate this metric should be included, rather than only described in words to make sure it is very clear what is being shown.*

Reply: We appreciate Reviewer's diligent examination of our original metric, proposing and detailed description of two new metrics we could use to evaluate the contribution of ARs to net SEB. As the Reviewer rightly pointed out, the main goal of this work is to estimate the relative contribution of different SEB components to the net SEB. To achieve this, we utilize original panel (c) in the Figures 2-3, 5-7 of the manuscript to illustrate the relative AR contribution to SEB components, normalized by the net SEB. This normalization involves calculating the ratio of the accumulated AR SEB term, which accounts for both the magnitude of individual AR anomalies and their frequency of occurrence, to the accumulated seasonal net SEB.

A relative contribution exceeding 100% indicates that the considered term has a greater AR contribution than the total SEB, implying that other SEB terms counteract to yield a small net SEB. Very large relative contributions indicate that the climatological SEB results from a small difference in large, oppositely signed terms in the SEB and that one of those large terms has a large AR signal. We believe that this is useful information to show since this normalization facilitates consistent comparison across different SEB components, allowing readers to discern relative contributions effectively. The inclusion of panel (b), depicting composite absolute AR-related SEB term anomalies adjacent to original panel (c), serves to remind readers to consider absolute anomaly values alongside relative contributions. Presenting both the anomaly (panel (b)) and relative contribution (original panel (c)) aims to provide readers a comprehensive perspective, highlighting terms that are large in both absolute and relative senses (e.g., downward longwave radiation over sea ice-covered central Arctic Ocean), as well as those that are small in absolute anomalies but substantial relative to the overall surface energy budget (e.g., SEB terms over continents).

We appreciate the Reviewer's suggestion to show each AR SEB term normalized by just the mean of that term and think that this is a very useful suggestion. As such we have included this with a slight modification as an additional panel (now panel (c)) in Figures 2, 3 and 5-7 and moved the AR SEB contribution normalized by the total SEB (original panel (c)) to panel (d). We have included the equations used to calculate these results of new panel (c) and (d) in Section 2 (Data and Methods) for transparency and clarity in the manuscript, as follows:

"Mathematically, the results shown in panel (c) result from the following calculation at each individual grid point within the study domain for each season:

I. *Calculate the total extra energy contributed by each SEB component when ARs are present as,* $(F_{AR} - F_{All}) * t_{AR}$, *where* F_{AR} *represents the mean of any term in the SEB equation when an AR is present,* F_{All} *denotes the seasonal mean of any term in the SEB equation (panel (a)), and* t_{AR} *indicates the total number of 3-hourly time steps during which ARs are present.*
II. *Calculate the total energy for each component as,* $F_{All} * t_{All}$, *where* t_{All} *signifies the total number of 3-hourly time steps within each season.*
III. *Determine the ratio of these two terms, which provides an estimate of the magnitude of AR anomaly for each SEB term relative to the average value for each component. This is presented in Eq. (2), noting that the ratio of* t_{AR} *to* t_{All} *is simply the AR frequency shown in Fig. 1.*

$$\frac{(F_{AR}-F_{All})* t_{AR}}{F_{All}*t_{All}} = \frac{panel\ (b) * Fig.1}{panel\ (a)} \tag{2}$$

Furthermore, the results depicted in panel (d) stem from the following calculation conducted at each individual grid point within the study domain for each season.:

I. *Calculate the total extra energy contributed by each term in the SEB equation when ARs are present as:* $(F_{AR} - F_{All}) * t_{AR}$
II. *Compute the absolute value of total SEB energy as:* $|netSEB_{All}| * t_{All}$, *where* $|netSEB_{All}|$ *represents the absolute value of seasonal mean net SEB at a given grid point.*
III. *The ratio of these two terms indicates the relative contribution of the AR anomaly for each SEB term to the total seasonal SEB, as shown in Eq (3).*

$\frac{(F_{AR}-F_{All}) * t_{AR}}{|net\ SEB_{All}| * t_{All}} = \frac{panel\ (b) * Fig.1}{|Fig.7(a)|}$ *(3)"*

The alternative solution presented in Equation 6 would yield results equivalent to $\frac{(LWD_{noAR}-LWD_{AR}) * t_{AR}}{SEB_{All} * t_{All}} = \frac{(LWD_{noAR}-LWD_{AR}) * \frac{t_{AR}}{t_{All}}}{SEB_{All}}$. This alternative approach also involves the net SEB as the denominator in the calculation, resulting in results greater/less than 100%/ -100%. After careful consideration, we decide to add the metric of each AR SEB term normalized by just the mean of that term (new panel (c)) and maintain our original metric of AR SEB contribution normalized by the total SEB (now panel (d)). The corresponding specific equations are provided in the manuscript, as stated above.

2. *I am unable to reproduce the "contribution to SEB" values shown in Table 1 using the description of how it was calculated in Section 2.3. Since the AR frequencies, anomalies and net SEB values are provided for each region, the contribution should be able to be calculated without any further information (based on Section 2.3). Please see the attached document for an example of this calculation not resulting in the same value seen in Table 1.*

Reply: We apologize for any lack of clarity in our methodology section. For each SEB term, we summarize key metrics in Table 1 and Table S1, such as AR occurrence frequency (Fig.1), climatology (panel a), composite anomalies (panel b), AR contribution to individual SEB component (panel c), and total AR contribution to absolute net SEB (now panel d). These results listed in the tables are derived from area-averaged calculations, which involves summing the results of grid points falling within each region and weighing them using the cosine values of their corresponding latitudes. Mathematically, the weighted average of a metric f over a grid with latitude θ can be represented as:

$$< f >= \frac{\sum_{i=1}^{n} w_i f_i}{\sum_{i=1}^{n} w_i}$$

where $< f >$ represents the weighted average of the metric f, f_i is the value of f at grid point i, w_i is the weight associated with the grid point i, which is the cosine of the latitude at that point, ($w_i = \cos(\theta_i)$), and n is the total number of grid points within each region.

The results of the relative contribution of AR LWD to absolute net SEB listed in Table 1 are calculated as bellow.

1. For each grid point i within a specific region during each season, we calculate the metric of f_i using Eq. (2):

$$f_i = \frac{(F_{AR,i} - F_{All,i}) * \frac{t_{AR,i}}{t_{All,i}}}{|net\ SEB_{All,i}|} = \frac{panel\ (b)_i * Fig.1_i}{|Fig.7(a)|_i}$$

2. We then multiply the value of f_i by the weight w_i ($w_i = \cos(\theta_i)$), resulting in $f_i * \cos(\theta_i)$

3. We sum up these products of $f_i * \cos(\theta_i)$ for all the grid points (n) within each region as $\sum_{i=1}^{n} f_i * \cos(\theta_i)$

4. This sum is divided by the total sum of weights: $< f >= \frac{\sum_{i=1}^{n} f_i * \cos(\theta_i)}{\sum_{i=1}^{n} \cos(\theta_i)}$

However, it is important to note that the weighted aera-averaged result of the relative contribution to net SEB using all the grid points within each season is not equivalent to the result calculated directly using the weighted average results of composite anomalies ($< Fig. 2b >$), AR frequency ($< Fig. 1 >$) and net SEB ($< Fig. 7a >$) listed in the table.
For example, the weighted average of composite LWD anomalies (Fig.2b) can be written as:

$$< Fig. 2b >= \frac{\sum_{i=1}^{n} Fig. 2b_i * \cos(\theta_i)}{\sum_{i=1}^{n} \cos(\theta_i)}$$

Similarly, the weighted average of AR occurrence frequency (Fig. 1) and net SEB (Fig. 7a) are calculated as:

$$< Fig. 1 >= \frac{\sum_{i=1}^{n} Fig. 1_i * \cos(\theta_i)}{\sum_{i=1}^{n} \cos(\theta_i)}$$

$$< Fig. 7a >= \frac{\sum_{i=1}^{n} Fig. 7a_i * \cos(\theta_i)}{\sum_{i=1}^{n} \cos(\theta_i)}$$

The weighted average of AR LWD contribution to absolute of net SEB can be written as:

$$< Fig. 2d >= \frac{\sum_{i=1}^{n} \frac{Fig. 2b_i * Fig1_i}{|Fig. 7a_i|} * \cos(\theta_i)}{\sum_{i=1}^{n} \cos(\theta_i)}$$

However, it is important to highlight that $\sum_{i=1}^{n} \frac{Fig.2b_i * Fig1_i}{|Fig.7a_i|} * cos\theta_i$ is not simply equivalent to $\frac{(\sum_{i=1}^{n} Fig.2b_i * cos\theta_i) * (\sum_{i=1}^{n} Fig.1_i * cos\theta_i)}{\sum_{i=1}^{n} |Fig.7a_i| * cos\theta_i}$

Thus, $< Fig. 2d > \neq \frac{<Fig.2b> * <Fig.1>}{<Fig.7a>}$

To illustrate, I provide a specific example of a few values to calculate the AR-related LWD contribution to the total net SEB, as mentioned by the Reviewer:

longitude (170 °E)	point i=1	point i=2	point i=3	point i=4	point i=5	point i=6	point i=7	point i=8	weighted results
Latitude (°N)	70	75	78	74	76	80	82	86	
$\boldsymbol{LWD_{AR} - LWD_{All}}$ $(\boldsymbol{W\,m^{-2}})$	29.8	30.1	32.3	28.7	31.7	31.5	31.7	32.4	30.7

$\frac{t_{AR}}{t_{All}}$ (%)	12.0	11.4	10.7	11.8	11.2	10.5	9.7	8.4	11.1
net SEB ($W\ m^{-2}$)	-8.3	-14.8	-15.8	-14.4	-15.4	-16.7	-17.8	-19.1	-14.3
$\frac{(F_{AR}-F_{All})*\frac{t_{AR}}{t_{All}}}{\lvert net\ SEB_{All}\rvert}$ (%)	43.1	23.2	21.9	23.5	23.1	19.8	17.3	14.2	25.9

Based on this example with just 8 grid points, the area-averaged result of the relative AR contribution to the net SEB is 25.9%; while directly using the weighted results will lead to the relative contribution of 30.7*11.1/14.3=23.8%. In fact, the total number of grid points for the four sub-regions range from 51844 to 85175, leading to much greater differences in the results using the two approaches mentioned before. The calculation of area-averaged results weighted by the cosine of latitudes accounts for the convergence of meridians towards the poles, ensuring a more accurate representation of the area-averaged results. Additionally, we have included the methods to calculate the results listed in the table in Section 2.3 for clarity, as follows:

"We summarize key features from Figures 2-3,5-7 into Table 1 and Table S1 to analyze each SEB component and the net SEB across four sub-regions: the central Arctic (including the Barents and Kara Seas), sub-polar oceans, continents, and Greenland (Fig. S1), for every season. These tables present regional averages for several metrics, including climatology (panels a), composite anomalies (panels b), AR contribution to individual SEB component (panels c), AR contribution to absolute net SEB (panels d), along with AR frequency (as shown in Fig.1). To derive these results, we perform area-averaged calculations by summing the values from grid points within each region and weighting them based on the cosine values of their corresponding latitudes. Additionally, we calculate the difference between the area-averaged AR contribution to the net SEB and the area-averaged AR frequency, representing additional AR contribution, which is presented in the last row of the tables."

3. *Consider performing statistical testing to determine if the absolute anomalies during ARs are statistically different from the mean conditions (which could be shown in the b rows of Figures 2-7). Since ARs exist in a location likely for more than one timestep, there is some temporal autocorrelation which may be accounted for by randomly selecting a smaller sample of AR timesteps to compare to a randomly selected sample of non-AR timesteps. Determining the statistical significance of these anomalies may help to identify SEB components that are more important with more confidence.*

Reply: While evaluating the statistical significance of these anomalies is indeed valuable for identifying AR-related important SEB components with greater confidence, we have concerns that labelling all the grid points within the confidence intervals may potentially overwhelm readers and make it hard to read. Therefore, we have decided to conduct statistical confidence intervals for the regional area-averaged results listed in Table 1 and Table S1 using the bootstrap method. We will indicate the results within the 95% (or 90%) confidence intervals by presenting them in bold text and adding them to the table caption. This approach aims to maintain clarity while still conveying the statistical confidence of our findings effectively.

Minor Comments:

45-46: ARs typically being associated with extratropical cyclones is mentioned here, but isn't discuss it again. I think more discussion regarding the linkage between cyclones and ARs would be valuable here for context of when/how ARs occur in the Arctic.

Reply: We have addressed your comments by expanding the discussion on the relationship between ARs and cyclones, particularly focusing on their association in the Arctic region, as follows:

"Atmospheric rivers (ARs) are long and narrow filaments of enhanced moisture transport typically associated with a low-level jet and extratropical cyclone (Ralph et al., 2018). In mid-latitudes, ARs are commonly identified in the warm conveyor belts of synoptic-scale cyclones, particularly low-level jets (Ralph et al., 2004, 2006). Some literature even considers ARs as part of cyclones (Bao et al., 2006; Neiman et al., 2008; Dacre et al., 2015). ARs and cyclones exhibit strong statistical and dynamic relationships (Zhang et al., 2019; Guo et al., 2020; Eiras-Barca et al., 2018). In the Arctic, poleward moisture transport is also closely linked to cyclone activity, including intensity, frequency, and duration (Villamil-Otero et al., 2018). Arctic cyclones account for over 70% of the average annual moisture transport, with their track orientation and upper-level steering flow significantly influencing poleward moisture flux (Fearon et al., 2021)."

100: It is mentioned that times are only used during neutral or weak El Niño-Southern Oscillation. I assume it's because of IVT anomalies associated with strong ENSO events, but it is worth briefly stating in the text for clarity.

Reply: We only preserved the dates during neutral or weak ENSO events to establish a standard climate threshold for testing ARs. For instance, in the event of updating the AR index to the MOSAiC year, we do not need to collect the data and recalculate the thresholds. To clarify this approach, we have included the following note in the manuscript:

"The selection of the neutral or weak ENSO events aim to establish a standard climate threshold for testing ARs."

123-125: Is it necessary to give multiple names for these first 3 ERA5 variables?

Reply: The term "surface thermal radiation downward", "surface net thermal radiation", and "surface net solar radiation" are the names provided in the original ERA5 source data. However, in the literature, the commonly used terms are "surface downward longwave radiation", "surface net longwave radiation", and "surface net shortwave radiation". We choose to use these commonly used names while also mentioning their origins in ERA5 for the benefit of readers who wish to replicate the results.

147-149: This sentence uses both "three-hourly" and "3-hourly" referring to the data – I suggest picking one to remain consistent.

Reply: We have selected "3-hourly" and replaced all instances of "three-hourly" to "3-hourly" throughout the manuscript.

287-289: What is meant by "ARs make their most significant relative contribution to the average net SEB in spring, accounting for at least 45% of the net SEB, surpassing the corresponding AR frequency by more than 34%"? I don't think subtracting the frequency from the contribution has a physical meaning since they are percentages of different things.

Reply: The difference between the area-averaged AR contribution to the net SEB and the area-averaged AR frequency, indicates additional AR contribution. The difference signifies the extent to which ARs contribute to the net SEB beyond their occurrence frequency.

358: I suggest starting a new paragraph at "The results over the central Arctic" as this is a long paragraph, and a new topic is being introduced here.

Reply: We have started a new paragraph for this topic.

Section 3 is titled "Analysis and Results" and Section 4 "Discussion", but Section 3 includes a lot of discussion (i.e., discussing potential impacts of the anomalies, comparing to previous work) and Section 4 still discusses some results (particularly temperature). A potential solution for this would be to rename Section 3 to focus on SEB and Section 4 to focus on impacts, and perhaps create another section for limitations/uncertainties (for 4.3 and 4.4)

Reply: We have taken this suggestion into account and restructured the manuscript accordingly. Therefore, the sections have been retitled as per the suggestion.

References

Bao, J. W., Michelson, S. A., Neiman, P. J., Ralph, F. M., and Wilczak, J. M.: Interpretation of enhanced integrated water vapor bands associated with extratropical cyclones: Their formation and connection to tropical moisture, Mon Weather Rev, 134, https://doi.org/10.1175/MWR3123.1, 2006.

Dacre, H. F., Clark, P. A., Martinez-Alvarado, O., Stringer, M. A., and Lavers, D. A.: How do atmospheric rivers form?, Bull Am Meteorol Soc, 96, https://doi.org/10.1175/BAMS-D-14-00031.1, 2015.

Eiras-Barca, J., Ramos, A. M., Pinto, J. G., Trigo, R. M., Liberato, M. L. R., and Miguez-Macho, G.: The concurrence of atmospheric rivers and explosive cyclogenesis in the North Atlantic and North Pacific basins, Earth System Dynamics, 9, https://doi.org/10.5194/esd-9-91-2018, 2018.

Fearon, M. G., Doyle, J. D., Ryglicki, D. R., Finocchio, P. M., and Sprenger, M.: The Role of Cyclones in Moisture Transport into the Arctic, https://doi.org/10.1029/2020GL090353, 2021.

Guo, Y., Shinoda, T., Guan, B., Waliser, D. E., and Chang, E. K. M.: Statistical relationship between atmospheric rivers and extratropical cyclones and anticyclones, J Clim, 33, https://doi.org/10.1175/JCLI-D-19-0126.1, 2020.

Neiman, P. J., Ralph, F. M., Wick, G. A., Lundquist, J. D., and Dettinger, M. D.: Meteorological characteristics and overland precipitation impacts of atmospheric rivers affecting the West coast of North America based on eight years of SSM/I satellite observations, J Hydrometeorol, 9, https://doi.org/10.1175/2007JHM855.1, 2008.

Ralph, F. M., Neiman, P. J., and Wick, G. A.: Satellite and CALJET aircraft observations of atmospheric rivers over the Eastern North Pacific Ocean during the winter of 1997/98, Mon Weather Rev, 132, https://doi.org/10.1175/1520-0493(2004)132<1721:SACAOO>2.0.CO;2, 2004.

Ralph, F. M., Neiman, P. J., Wick, G. A., Gutman, S. I., Dettinger, M. D., Cayan, D. R., and White, A. B.: Flooding on California’s Russian River: Role of atmospheric rivers, Geophys Res Lett, 33, https://doi.org/10.1029/2006GL026689, 2006.

Ralph, F. M., Dettinger, M. C. L. D., Cairns, M. M., Galarneau, T. J., and Eylander, J.: Defining “Atmospheric river" : How the glossary of meteorology helped resolve a debate, Bull Am Meteorol Soc, 99, https://doi.org/10.1175/BAMS-D-17-0157.1, 2018.

Villamil-Otero, G. A., Zhang, J., He, J., and Zhang, X.: Role of extratropical cyclones in the recently observed increase in poleward moisture transport into the Arctic Ocean, Adv Atmos Sci, 35, https://doi.org/10.1007/s00376-017-7116-0, 2018.

Zhang, Z., Ralph, F. M., and Zheng, M.: The Relationship Between Extratropical Cyclone Strength and Atmospheric River Intensity and Position, Geophys Res Lett, 46, https://doi.org/10.1029/2018GL079071, 2019.